

STUDY OF THE POSSIBILITY OF SUPERNARROW DIBARYON PRODUCTION IN THE $\vec{\gamma}d \rightarrow \pi^\pm + D$ REACTIONS

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Abstract

The possibility of observation of supernarrow dibaryons, decay of which into two nucleons forbidden by the Pauli principle, produced in processes of charged pion photoproduction by polarized photons from the deuteron is analyzed. It is shown that the expectable dibaryon yield may exceed the background by a factor of 10–100.

The possibility of existence of multi-quark states is predicted by QCD [1]. This is a new type of matter. The experimental discovery of such states might have serious consequences for both elementary particle physics and nuclear physics. A search for narrow 6-quark states (dibaryons) is being carried out for a long time (see, e.g., [2, 3]), and a number of candidates for these states has been found. However, up to the present day, one can hardly unambiguously state that the features found in these experiments were indeed dibaryons. This associated, first of all, with a relatively low contribution of dibaryons to the processes under study and the uncertainty of the contribution of the background processes.

We propose to seek for supernarrow dibaryons whose decay into two nucleons is forbidden by the Pauli principle [4, 5, 6, 7, 8, 9]. Such dibaryons satisfy the condition

$$(-1)^{T+S}P = +1, \quad (1)$$

where T is the isotopic spin, S is the internal spin, and P is the parity of the dibaryon. These dibaryons with mass $M < 2m_N + \mu$ (m_N is the nucleon mass and μ is the pion mass) can mainly decay into two nucleons with photon emission. The contributions of such dibaryons to processes of strong interactions of hadrons are very low. However, their contributions to processes of electromagnetic interactions on light nuclei may be several orders of magnitude higher than the values of cross sections of these processes out of the resonance [4, 5, 7].

In the present paper we study the possibility of observation of supernarrow dibaryons $D(T = 1, J^P = 1^+, S = 1)$ and $D(T = 1, J^P = 1^-, 0)$ having the mass $M < 2m_N + \mu$ and satisfying the condition (1) in the processes of π^\pm meson photoproduction by polarized photons from the deuteron

$$\vec{\gamma} + d \rightarrow \pi^\pm + D, D \rightarrow \gamma NN. \quad (2)$$

The dibaryons under consideration have very small decay widths. Their values, calculated under assumption that γNN decay of the dibaryons goes on mainly through the singlet virtual 3S_0 level in the intermediate state, are presented in Table 1 [7].

Table 1: Decay widths of $D(1, 1^+, 1)$ and $D(1, 1^-, 0)$ dibaryons for different dibaryon masses M . $\Gamma_t \simeq \Gamma_{\gamma NN}$.

$M \text{ (GeV)}$	1.90	1.91	1.93	1.95	1.98	2.00	2.013
$\Gamma_t(1, 1^+)$ (eV)	0.2	0.52	2.2	5.8	16	26	35
$\Gamma_t(1, 1^-)$ (eV)	0.05	0.13	0.55	1.46	4	6.5	8.75

For the processes (2) the dibaryons can only be produced under condition when the overlap of the nucleons inside the deuteron is so strong that a 6-quark state with deuteron quantum numbers is formed. In this case, the interaction of a photon or a pion with this state can so change its quantum numbers that a metastable state satisfying the condition (1) is formed. Because of this the probability of such dibaryon productions proportional to the probability η of existence of the 6-quark state in the deuteron. The evaluation of η from the difference between the theoretical and the experimental values of the deuteron magnetic moment gives $\eta \leq 0.03$ [10]. We assume here that $\eta = 0.01$.

Let us consider the photoproduction of dibaryons by photons polarized at an angle α where

$$\cos \alpha = \frac{(\vec{\epsilon}[\vec{k}_1 \vec{q}_1])}{\nu q},$$

$\vec{\epsilon}$ and \vec{k}_1 are the plarization and momentum vectors of an incident photon, ν is its energy, \vec{q}_1 and q are the momentum vector of a pion formed in the reaction and its absolute value (in lab. system).

Let us restrict our consideration to the dibaryon formation in the process of π^+ meson photoproduction. The calculation of photoproduction of the dibaryons in the combination with π^- mesons gives a qualitatively similar result. The calculations made in the framework of the model [9] give the following expression for the $D(1, 1^-, 0)$ dibaryon production cross section in the $\vec{\gamma} + d \rightarrow \pi^+ + D(1, 1^-, 0)$ process (in lab. system):

$$\frac{d\sigma_{\vec{\gamma} \rightarrow \pi^+ D(1, 1^-, 0)}}{d\Omega} = \frac{2}{3} \left(\frac{e^2}{4\pi} \right) \left(\frac{g_1^2}{4\pi} \right) \eta \frac{q^2}{m_d M^2 \nu J} \left\{ |\vec{r}|^2 + \right. \quad (3)$$

$$\left. q^2 \sin^2 \theta_\pi \sin^2 \alpha \left[1 - 8 \frac{m_d r_0}{\mu^2 - t} + 4 m_d^2 \frac{M^2 + 2 r_0^2}{(\mu^2 - t)^2} \right] \right\},$$

where $t = \mu^2 - 2\nu(q_0 - q \cos \theta_\pi)$, $J = q(m_d + \nu) - q_0 \nu \cos \theta_\pi$, m_d is the deuteron mass, $q_0(q)$ is the pion energy (momentum),

$$q_0 = \frac{1}{c_1} \left[(m_d + \nu) c_2 \pm \nu \cos \theta_\pi \sqrt{c_2^2 - 2\mu^2 c_1} \right],$$

$$c_1 = 2[(m_d + \nu)^2 - \nu^2 \cos^2 \theta_\pi], \quad c_2 = s + \mu^2 - M^2.$$

The dibaryon energy r_0 and momentum $|\vec{r}|$ are given by $r_0 = m_d + \nu - q_0$ and $|\vec{r}| = \sqrt{r_0^2 - M^2}$, respectively.

The $D(1, 1^+, 1)$ dibaryon production cross section has the form

$$\frac{d\sigma_{\gamma d \rightarrow \pi^+ D(1, 1^+, 1)}}{d\Omega} = \frac{16}{3} \left(\frac{e^2}{4\pi} \right) \left(\frac{g_2^2}{4\pi} \right) \eta \frac{q^2}{m_d M^2 \nu J} \left\{ M^2 + q^2 \sin^2 \theta_\pi \sin^2 \alpha \left[1 - 4 \frac{m_d r_0}{\mu^2 - t} + 4 \frac{m_d^2 |\vec{r}|^2}{(\mu^2 - t)^2} \right] \right\}. \quad (4)$$

The values of $g_1^2/4\pi$ and $g_2^2/4\pi$ are unknown. These are the constants of strong interaction. Let us set them equal to 1 lest the cross section values should be overstated. To evaluate the contribution of the dibaryons for different values of the mass M , we assume the possibility of the existence of the dibaryons with the masses $M=1.9, 1.95$, and 2.00 GeV .

We carried out a numerical analysis of the cross section for photoproduction of the dibaryons by photons polarized parallel ($\alpha = 90^\circ$) and perpendicular ($\alpha = 0^\circ$) to the reaction plane. As follows from the calculations, the $D(1, 1^-, 0)$ dibaryon photoproduction cross section has a strong dependence on the photon polarization. For the photons polarized in the reaction plane it is large and, at least in the range of angles $\theta = 10^\circ - 50^\circ$, substantially exceeds the $D(1, 1^+, 1)$ dibaryon photoproduction cross section, whereas the cross section for the photons polarized perpendicular to the reaction plane is very small.

The dependence of the $D(1, 1^+, 1)$ dibaryon photoproduction cross section on the photon polarization is considerably weaker. This is caused by smallness of the factor $|\vec{r}|^2$ in the latter term of expression (4).

The CLAS detector of charged and neutral particles in combination with the tagging system of the CEBAF accelerator offer perfect potentialities for the search and study of supernarrow dibaryons in the reactions under consideration. This setup enables one to seek for the dibaryons by way to detecting charged pions with a wide-aperture magnetic spectrometer and separating out peaks in the spectrum of missing masses. An additional detection of the photon produced through the dibaryon decay, in coincidences with the pion, provides a substantial suppression of the contribution of background reactions to this spectrum.

The main background reaction in which a photon is produced in the final state are the photoproduction of two pions ($\gamma d \rightarrow \pi^+ + \pi^0 + nn$, $\pi^0 \rightarrow \gamma\gamma$) and the radiative photoproduction of a π^+ meson ($\gamma d \rightarrow \pi^+ + \gamma + nn$). When estimating the contribution of the background reactions, we assumed that they had only a weak dependence on the photon polarization.

Using the Monte-Carlo method, we performed simulation of the dibaryon photoproduction and the main background reactions on the deuteron target 20 cm long on the setup mentioned above under real conditions. The energy of the initial photons was taken in the range of 500–1000 MeV.

Fig.1 illustrates the spectrum of missing masses which was obtained in this simulation for 5 hours of the accelerator work. The expected yields of the dibaryons with different masses are listed in Table 2.

Among two background processes considered, the contribution to the mass range $M < 2m_N + \mu$ being studied is given by the radiative photoproduction only.

Table 2: Expected yields of the dibaryons produced in the $\vec{\gamma}d \rightarrow \pi^+D$ process during 5 hours of accelerator work.

	α	$M = 1.90 \text{ GeV}$	$M = 1.95 \text{ GeV}$	$M = 2.00 \text{ GeV}$
$D(1, 1^+, 1)$	90°	386	370	351
	0°	443	437	381
$D(1, 1^-, 0)$	90°	3901	3552	3165
	0°	7	5	3

As seen from Fig.1 and Table 2 the contribution of the dibaryons may exceed the background by a factor of 10–100. For $\alpha = 90^\circ$, the yield of $D(1, 1^-, 0)$ dibaryons must exceed the yield of $D(1, 1^+, 1)$ dibaryons by about a factor of ten. For $\alpha = 0^\circ$, the production of $D(1, 1^-, 0)$ dibaryons is strongly suppressed (a 5-hour exposure is expected to give only a few events). From the comparison with the dibaryon production by unpolarized photons it follows that the excess of the yield of $D(1, 1^-, 0)$ dibaryons produced by polarized photons over the background is several times greater than the corresponding excess for unpolarized photons.

Thus, the use of a polarized photon beam makes it possible to increase the contributions of the dibaryons to the mass spectrum in comparison with the contribution of the background and to determine the dibaryon quantum numbers. Additional information on these quantum numbers can be obtained from the analysis of the angular distributions of the differential cross sections for the dibaryon photoproduction.

If the dibaryons are detected in the process of π^+ meson photoproduction from the deuteron, they will have to be observed in the $\vec{\gamma}d \rightarrow \pi^-D$ reaction as well. The observation of dibaryons in both reactions will allow to make a conclusion about the production of the supernarrow dibaryons satisfying the condition (1) more unambiguously. Moreover, this will enable one to determine the possible electromagnetic splitting of their masses and obtain additional conditions for determining the dibaryon quantum numbers.

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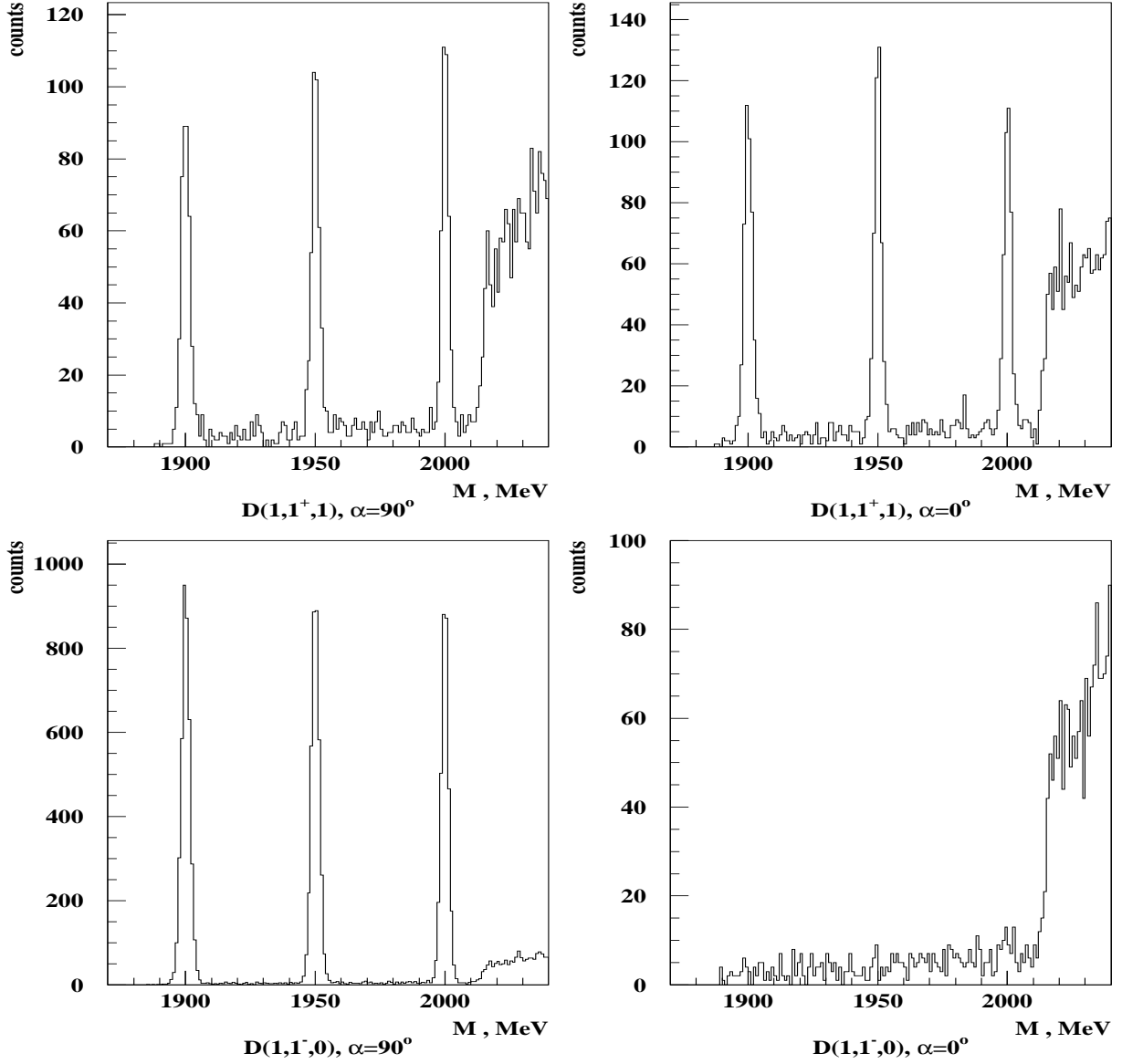


Figure 1: Spectra of missing masses expected for the $D(1,1^+,1)$ and $D(1,1^-,0)$ dibaryons produced by photons polarized at the angles $\alpha = 0^\circ$ and 90° from the deuteron and for the main background processes.